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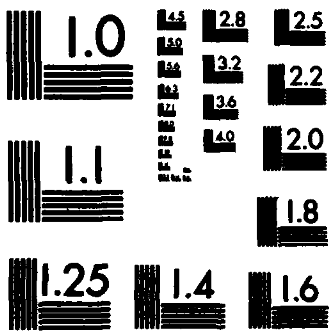

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AFOSR-TR- 83-1016

AFOSR Grant Number 82-0144
Final Technical Report
May 1983

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VISUAL CUES IN THE SIMULATION
OF LOW LEVEL FLIGHT

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Controlling Office: USAF Office of Scientific Research/NL
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SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered) UNCLASSIFIED

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER AFOSR-TR- 83-1016	2. GOVT ACCESSION NO. AD-A135 461	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) Visual Cues in the Simulation of Low-Level Flight		5. TYPE OF REPORT & PERIOD COVERED Final Report Apr.1, 1982-Mar.31, 1983
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) Edward J. Rinalducci		8. CONTRACT OR GRANT NUMBER(s) ~~AFOSR Grant No.82-0144~~ AFOSR-82-0144
9. PERFORMING ORGANIZATION NAME AND ADDRESS School of Psychology Georgia Institute of Technology Atlanta, GA 30332		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS 2313/A9 61102F
11. CONTROLLING OFFICE NAME AND ADDRESS Air Force Office of Scientific Research/NL Bolling Air Foce Base, DC 20332		12. REPORT DATE May 31, 1983
		13. NUMBER OF PAGES 30
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)		15. SECURITY CLASS. (of this report) UNCLASSIFIED
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release;
distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

visual cues, low level flight simulation, terrain features, detail, density, vertical development, static mode of presentation, dynamic mode of presentation, CIG,

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The research described in this report was directed towards an examination of visual cues used by pilots to maintain altitude in low level flight simulation. The first study investigated the use of a psychophysical technique to provide a quick, low-cost evaluation of altitude cues provided by five visual display system conditions in which terrain features were varied in detail, density, and vertical development. Both pilot and non-pilot observers were employed. Differences between pilots and non-pilots existed for the

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VISUAL CUES IN THE SIMULATION OF LOW LEVEL FLIGHT

Dr. Edward J. Rinalducci, Ph.D.

ABSTRACT

The research described in this report was directed towards a continued examination of visual cues used by pilots to maintain altitude in low level flight simulation. The first study investigated the use of a psychophysical technique to provide a quick, low-cost evaluation of altitude cues provided by five visual display system conditions in which terrain features were varied in detail, density, and vertical development. Both pilot and non-pilot observers were employed. Differences between pilots and non-pilots existed for the accuracy of altitude estimation, but the rankings of the effectiveness of the visual environments were the same for both groups. These results indicate that the use of non-pilot subjects can contribute to the overall cost-effectiveness and development of future simulator displays. A second study examined three visual display environments (i.e., a valley floor, a valley floor with walls, and a valley floor with walls and inverted pyramids) using different display modes (i.e., slides, static video, and dynamic video). Both pilot and non-pilot subjects were employed. Again, differences between pilot and non-pilot subjects were obtained for the accuracy of altitude estimation, with the former being more accurate. Although the results were complex, both pilots and non-pilots showed, in general, an improvement in altitude estimation with the dynamic vs. the static mode of presentation and with increasing complexity

in the visual scene. The results of both studies have relevance to the development of CIG and the evaluation of simulator visual environments.

I. INTRODUCTION:

Important visual factors are involved in flight simulation and the training of pilots. The various tasks especially required of U. S. Air Force pilots which involve these visual factors include formation flying and aerial refueling, low level flight, weapons delivery, and approach and landing. There has also been a growing emphasis in pilot training on the simulation of low level flight. This has lead to an increased research effort into the nature of the visual cues required by pilots to maintain altitude. Evaluation of the necessary visual cues has been primarily accomplished through simulator flying studies. However, such studies can be costly and time consuming, and often produce equivocal results. The research discussed below is directed toward the various aspects of visual space perception and information processing relevant to visual flight simulation and techniques which could contribute to the overall cost-effectiveness and development of future simulator displays.

Depth perception has obvious relevance to visual flight simulation and the maintenance of altitude in flight. Pilots must be able to learn to judge their altitude with some accuracy especially in low level flight operations. Outside the primary cue of retinal disparity there are the secondary cues of aerial perspective, linear perspective, retinal image and familiar size, texture gradient, motion parallax, streaming, interposition or overlay, height of an object in the visual field, light and shadows, as well as the physiological cues of accommodation and convergence (Graham, 1966; Harker and Jones, 1980). With regard to flight training and simulation some of these and

related cues are more important than others, especially when viewing a dynamic scene. Stenger, Zimmerlin, Thomas, and Braunstein (1981) and Harker and Jones (1980) in recent reports cite texture as a very important terrain feature in the dynamic simulator or flight environment and in the maintenance of low level flight. Unique terrain features and surface detail enables a pilot to keep track of his position and estimate altitude. For example, data obtained by this investigator (Rinalducci, 1981; Rinalducci, Martin, and Longridge, 1982) showed that vertical development of terrain features in a simulator is of considerable importance in the maintenance of altitude in low level flight. In this study (conducted in the F-16 cockpit of the Advanced Simulator for Pilot Training or ASPT located at Williams AFB) terrain features in the form of black vs. white topped inverted pyramids, the presence (or absence) of vertical development, and the effects of airspeed were investigated using pilots who varied in flying experience. Less experienced pilots (i.e., just out of Undergraduate Pilot Training or UPT) demonstrated increases in their mean altitude and RMS deviation (assigned altitude was 200 feet) with either an increase in airspeed or an increase in airspeed combined with a lack of vertical development in terrain features. Experienced pilots (i.e., those transitioning from other aircraft), on the other hand, only showed increases in mean altitude and RMS deviation with an increase in airspeed. Vertical development was, therefore, of particular importance to the less experienced pilots. No differences were

found between black vs. white topped pyramids, although white topped pyramids were generally preferred.

The research reported below was directed towards a continued examination of visual cues used by pilots to maintain altitude in low level flight simulation. The first study investigated the use of a psychophysical technique to provide a quick, low-cost evaluation of altitude cues provided by five visual display system conditions in which terrain features were varied in detail, density, and vertical development. Both pilot and non-pilot observers were employed. The second study examined three visual display environments using three different display modes. The display modes involved both static and dynamic presentations of the display environments. Again, both pilot and non-pilot subjects were employed.

II. EXPERIMENT 1:

As indicated above, there has been a growing emphasis in pilot training on the simulation of low level flight. The simulator visual system presents the pilot with a variety of cues he needs to perform his task. These range from airspeed, altitude, and navigation cues to those cues relating to the presence, distance, and behavior of threats and targets. Simulator flying studies have been performed to determine the effectiveness of texture (Edwards, Pohlman, Buckland, and Stephens, 1981), color (Kellogg, Kennedy, and Woodruff, 1981), and three-dimensional objects (Rinalducci, Martin, and Longridge, 1982), in providing low-altitude cues. While such studies provide the ultimate measure

of the effectiveness of a visual display in producing cues needed to perform simulated flight tasks, they have limitations. For example, the requirements of such studies for simulator time, subject time, and development time are great. Simply to study the effectiveness of one type of visual cue can requireas much as 50 hours of simulator time, even if only a small number of subjects is run. Therefore, only a limited number of visual environment displays may be investigated. In order to perform the parametric studies required for the design of effective simulator visual environments, techniques are required for assessing the cueing effectiveness of visual displays quickly and at low cost. Such techniques might be used to screen candidate displays so that only the most effective need to be examined in more comprehensive simulator flight studies.

The purpose of the first experiment was three-fold. The primary objective was to determine the effectiveness of a methodology for assessing the quality of simulator visual displays quickly and at low cost. The technique investigated involved having both pilot and non-pilot subjects estimate altitude (AGL) in static (slide) presentations of a simulator visual system display. This technique permits a cost-effective evaluation of visual displays but does not allow examination of the capability of visual scenes to provide altitude cues based on scene dynamics.

A second objective of the study was to examine aspects of scene content in order to determine their effects on the perception of altitude. Two aspects of visual scene content were

investigated. These were the density of three-dimensional objects in the environment and the level of detail of the objects.

Finally, a third objective was to examine the differences in performance between pilot and non-pilot subjects. The data to be obtained should indicate the usefulness of non-pilots to the overall cost-effectiveness and development of future simulator displays.

METHOD

Materials

Stimulus materials were 35 mm color slides taken with a 90° field-of-view lens in the F-16 cockpit of the Advanced Simulator for Pilot Training (ASPT) at Williams Air Force Base. The out-of-cockpit scene consisted of a flat terrain with 450-foot aiming towers at eight-mile separations. Display condition 1 and 3 were high detail conditions in which the sides of inverted pyramids (or tetrahedrons) were black and the base (top) was white. Conditions 2 and 4 were medium or moderate detail conditions in which the inverted pyramids were all black. Two conditions (1 and 2) were high object density conditions with mean distance between the inverted pyramids equal to about 1500 feet. In the low density conditions (conditions 3 and 4), separation between pyramids was 4500 feet. In all four conditions the pyramids were 50 feet tall. A fifth condition (condition 5) was intended to have the lowest detail. In this condition, the pyramids were displayed so that only the base was visible above the ground. Thus the pyramid had the appearance of a triangle laying flat on the ground (i.e., no vertical development).

Unfortunately, the level of detail was so low that the triangles appeared only as scintillations in the dynamic scene as the objects moved across the raster lines of the CRT display and were nearly invisible in the static display. As a result, only the 200-foot aiming towers provided any real altitude cues. The inverted pyramids were developed as terrain features for the study of low level flight operations in the ASPT (Martin and Rinalducci, in preparation). It should also be noted that the visual display system of the ASPT at the time of the present study was monochrome in nature.

In all conditions, eight altitudes ranging from 50 to 400 feet in 50-foot increments, were presented. A single set of 40 slides was used in which each of the 40 altitude-display condition combinations occurred once in a random sequence.

<u>Subjects</u>

Thirty pilots in A-10 combat crew training and thirty non-pilots from the undergraduate student population of the Georgia Institute of Technology served as subjects. The flying experience of the pilots ranged from approximately 400 to 3000 hours. None of the pilots had any previous flying experience in the ASPT.

<u>Procedure</u>

Pilot and non-pilot subjects were run separately in groups of ten. Subjects were seated from 15 to 25 feet from the screen image, which was 7½ feet wide. At the beginning of the session, the experimenter explained the purpose of the research and that

a sequence of 40 slides showing straight and level flight would be presented. Subjects were told that the slides would show five different simulator environments. Since none of the subjects had ASPT experience, they were told that the range of altitudes would be 50 to 400 feet. Subjects were not informed of the size of the inverted pyramids since no attempt was made to equate the size of the static display with that in the ASPT cockpit. Subjects were then given response sheets and told that when the first slide appeared, they were to estimate the altitude above the ground level (AGL) shown. Estimates for subsequent slides were to be made relative to the first. That is, if the estimated altitude for the first slide was 100 feet and the second slide appeared to have been taken from an altitude twice as high, the second estimate should be 200 feet, and so on for succeeding slides. Thus, the psychophysical method employed was a variation of magnitude estimation using a free modulus technique (Engen, 1972; Stevens, 1975). Each slide was presented for eight seconds with the interval between slides being only the cycle time of the projector (Kodak Ektagraphic). Both groups of subjects (pilots and non-pilots) were treated as similarly as possible so that any differences that might be obtained would not be due to the procedures used.

RESULTS

The first slide presentation sequence was treated as practice and the altitude estimates from the second and third runs only were analyzed. A linear regression function was

determined relating log estimated altitude to log actual altitude for each of the five display conditions. The least squares technique was used to solve for the slope and y-intercept of the linear regression function. The dependent measure analyzed was the slope of the linear regression function which is the exponent (n) of the power function ($S = kI^n$) obtained for each subject. The exponents were treated as individual data points. The values of the y-intercept were not analyzed. The data for both groups of subjects are shown in Figure 1 and in Table 1.

Table 1

Power Function Exponents of the Altitude Estimation Functions for the Five Visual Display Conditions

Condition	Object Density	Object Detail	Pilot Exponents	Non-Pilot Exponents
1 (white topped pyramids)	high	high	0.82	0.53
2 (all black pyramids)	high	medium	0.72	0.42
3 (white topped pyramids)	low	high	0.53	0.26
4 (all black pyramids)	low	medium	0.48	0.21
5 (white triangles on ground)	low	low	0.21	0.08

A 2 x 5 split-plot analysis of variance (Edwards, 1968) was performed on the data. The between-subjects variable consisted of two levels of flying or piloting experience (i.e., pilots vs. non-pilots). The within-subjects variable consisted of the

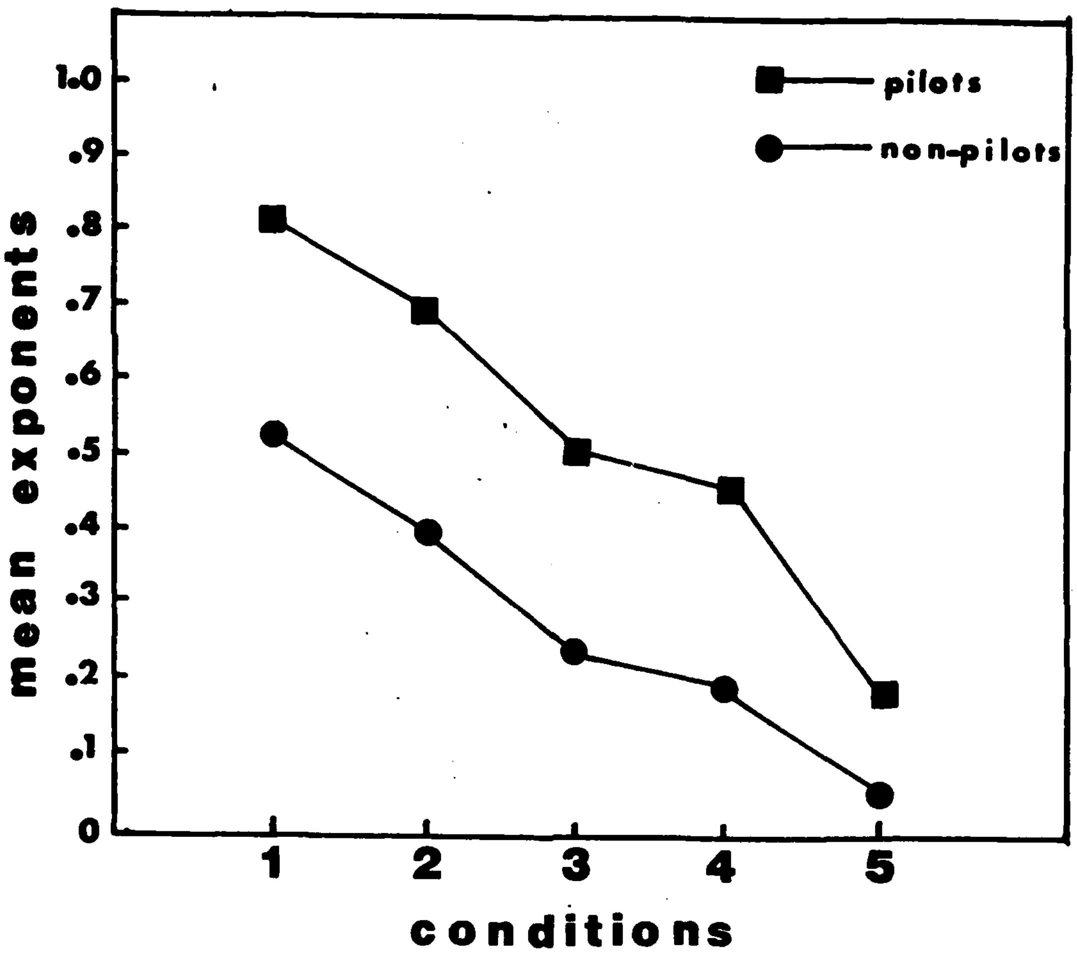

Figure 1. Mean exponents for pilots and non-pilots plotted as a function of visual display conditions.

five display conditions. A significant effect was obtained for both flying experience with a $F(1, 58) = 45.12$ (p less than 0.001) and for display conditions with a $F(4, 232) = 32.10$ (p less than 0.001). This is shown in Table 2.

Table 2

Analysis of Variance Table for Flight Experience x Display Condition

Source	SS	df	MS	F
Between subjects	20.12	59		
Flying experience	8.80	1	8.80	45.12*
Sub. w. groups	11.32	58	0.195	
Within subjects	27.04	240		
Display conds.	9.55	4	2.38	32.10*
Exp. x conds.	0.53	4	0.133	1.78
Conds. x sub. wgrps.	17.26	232	0.0743	

*p less than 0.001

In terms of the power function, an exponent (or slope of the log-log plot of the linear regression function) of 1.0 is indicative of accurate estimation of altitude. An exponent greater than 1.0 is indicative of expansion or overestimation of changes in altitude and an exponent of less than 1.0 is indicative of compression or underestimation of changes in altitude. The exponents for both groups of subjects showed considerable underestimation of altitude across all conditions (see Figure 1 and Table 1). The low detail, low density scene (condition 5) showed the greatest underestimation for both groups. The best altitude estimation for both groups occurred in the high detail, high density condition (condition 1). Both groups of subjects showed identical rankings of the

simulated environments in terms of the power function exponent.

Tukey HSD tests (Kirk, 1968) were performed at the 0.05 level in order to compare statistical differences between pilot and non-pilot altitude estimations (i.e., in terms of the exponents) for each display condition. The Tukey HSD tests were also performed to compare in a pairwise manner the means for each display condition for the grouped data (pilot and non-pilot subjects). The data of pilots and non-pilots were combined as both groups showed the same rankings of display conditions. Table 3 shows the results of the Tukey HSD tests for the grouped data.

Table 3

Differences Among Means

Conditions	1	2	3	4	5
1		N.S.	8.02*	9.40*	15.31*
2			5.02*	6.40*	12.31*
3				N.S.	7.29*
4					5.91*
5					

*p less than 0.05

In general, pilots displayed significantly better estimation performance for all conditions with the exception of condition 5. The difference in performance between pilots and non-pilots for this condition was found not to be statistically significant. Excluding condition 5, it can be seen from Table 3

that object density is an important cue to accurate altitude estimation as shown by the significant differences obtained between conditions 1 and 3 and 2 and 4 in which object detail was held constant but object density was varied. Object detail in the form of white topped pyramids vs. all black pyramids does not appear to be an important cue. This is shown by comparing conditions 1 and 2 and 3 and 4 where object density is held constant and object detail is varied. Here no significant differences were obtained.

DISCUSSION

In general, the method of magnitude estimation has been shown to be a sensitive technique for the evaluation of simulator display systems. The values of power function exponents varied as a function of object density and to some extent as a function of object detail.

The present data give no indication of the validity of the approach for making judgments about the effect of visual scene content on simulator flying performance. To determine the validity of the technique, it is necessary to compare the results of the present study with those of a simulator flying study. Rinalducci, Martin, and Longridge (1982) performed a simulator flying study on the ASPT using three of the visual environments employed in the present study (conditions 1, 2, and 5). The ability to maintain a constant altitude of 200 feet AGL was monitored while flying a prescribed course through each environment. Although variability in performance was high, significant differences

were obtained between conditions 1 and 5 and between conditions 2 and 5, but no significant differences were obtained between conditions 1 and 2. These findings pertain to relatively inexperienced pilots flying at an airspeed of 540 KIAS. The similarity between the results of the present study and those obtained by Rinalducci et al (1982) suggests that the magnitude estimation technique is sensitive to the effects of altitude cues needed for simulator flight.

In terms of terrain features, object density and object detail (particularly in the form of vertical development) appear to be important cues for altitude estimation. These findings were obtained for both pilot and non-pilot subjects who demonstrated similar rankings for the five display conditions. Thus, the use of non-pilot subjects to evaluate simulator visual environments could be a useful and cost-effective measure.

III. EXPERIMENT 2:

The second experiment examined the influence of the dynamic mode of presentation of a simulator visual environment compared to a static presentation. Static scene presentation refers to the use of still photographs (35 mm slides) or video projection (i.e., without movement). Dynamic visual scene presentation refers to visual scenes with motion such as that presented through video projection (i.e., with movement). It has generally been assumed that the presentation of terrain features and depth cues in a dynamic scene is preferable to a static scene, especially

when examining various aspects of visual space perception and visual information processing relevant to flight simulation. Empirical support on this issue, however, is lacking, and the present study provides relevant data. It was hypothesized that altitude estimates in a dynamic scene mode of presentation would be more accurate than those made from a static scene presentation. As in the first experiment, both pilot and non-pilot observers were employed.

METHOD

Materials

Stimulus materials consisted of 35 mm slides and video taped simulated flight segments. Slides were taken with a 90° field-of-view lens in the F-16 cockpit of the ASPT. Video tapes of 5-second flight segments through three simulated visual environments were also made. Airspeed for the dynamic mode of presentation was 450 KIAS. Slides and tapes were made for eight altitudes between 50 and 400 feet and separated by equal log intervals (i.e., about 0.13 log units). There were three display modes consisting of slides, dynamic video, and static video (still frames from the dynamic portion of the flight segment). There were also three visual display environments or conditions. Display environment 1 was a textured valley floor, environment 2 was a valley floor with walls, and environment 3 was a valley floor with walls and inverted pyramids. The pyramids had black sides with white tops and were of the same dimensions and distribution density as in experiment 1.

Eight altitudes were presented for the three visual display environments or conditions for a total of 24 slides, 24 static video frames, and 24 dynamic video flight segments. The display environments were randomized within each display mode and presented three times.

Subjects

Twenty-one pilots undergoing simulator training at Williams AFB and 24 non-pilots (i.e., undergraduate students at Georgia Tech) served as subjects in this tudy. The flying experiences of the pilots were similar to those participating in experiment 1.

Procedure

At the beginning of each session, the experimenter explained the purpose of the research and that a sequence of 24 slides, static video frames, or dynamic video flight segments would be presented. Subjects were told that the presentations would show three different simulator environments. Since none of the subjects had ASPT experience, they were told that the range of altitudes would be 50 to 400 feet. Subjects were then given response sheets and told when the first visual display environment was shown, they were to estimate the altitude above the ground level (AGL) shown. Estimates for subsequent visual environments were to be made relative to the first. In other words, the same psychophysical method employed in the first experiment (i.e., a variation of magnitude estimation using a free modulus technique) was used in the second experiment. Each slide was presented for eight seconds. Each static video frame was presented for eight seconds and each dynamic flight

segment was presented for five seconds. Due to time limitations, the pilot subjects were only partially counterbalanced for display modes with slides followed by dynamic video followed by static video frames for one group and dynamic video presentations followed by slides followed by static video for the second group. In contrast, the non-pilot subjects were completely counterbalanced for the three display modes producing six orders of display mode presentation.

RESULTS

The first display mode presentation sequence was treated as practice and the altitude estimates from the second and third runs only were analyzed. A linear regression function was determined relating log estimated altitude to log actual altitude for each display mode-display environment combination. The least squares technique was used to solve for the slope of the linear regression function. The dependent measure analyzed was again the slope of the linear regression function which is the slope of the power function obtained for each subject. The exponents were treated as individual data points. The data for both groups of subjects are shown in Figure 2 and in Table 4.

Table 4

Power Function Exponents of the Altitude Estimation Functions for the Static and Dynamic Visual Display Conditions

Display Environment	Slides	Static Video	Dynamic Video
Valley Floor	0.20 (0.37)*	0.007 (0.29)	0.26 (0.72)
Valley Floor with Walls	0.27 (0.54)	0.17 (0.58)	0.38 (0.61)
Valley Floor with Walls and Inverted Pyramids	0.59 (0.78)	0.26 (0.55)	0.53 (0.84)

*Pilot data in parentheses

A 2 x 3 x 3 split-plot analysis of variance was performed on the data. The ANOVA for the data showed statistically significant differences (p less than 0.0001) for both the two within subject variables (display mode and display environment) and for the between subject variable (flight experience). The results of this analysis are presented in Table 5. The means of each group for all conditions are shown graphically in Figure 2.

Table 5

Analysis of Variance of Pilot and Non-Pilot Altitude Estimates Across Display Modes and Environments

Source	df	MS	F	p less than
Flight Experience	1	8.431	31.76	0.0001
Error	43	0.265		
Display Mode	2	2.138	40.63	0.0001
Display Mode x Flight Ex.	2	0.171	3.26	0.06
Error	86	0.052		
Environment	2	2.748	46.51	0.0001
Environ. x Flight Ex.	2	0.015	0.25	0.79
Error	86	0.059		

Display Mode x Environment	4	0.301	10.15	0.0001
Display Mode x Environment x Flight Ex.	4	0.107	3/62	0.01
Error	172	0.029		

Separate two-way ANOVAs were performed on both the pilot and non-pilot data in order to clarify the locus of the higher order interactions. The results of these analyses are presented in Tables 6 and 7 below.

Table 6

Analysis of Variance of Pilots' Altitude Estimates Across Display Modes and Environments

Source	df	MS	F	p less than
Display Mode	2	1.052	27.52	0.0001
Error	40	0.038		
Environment	2	1.128	17.10	0.0001
Error	40	0.066		
Display Mode x Environment	4	0.298	11.24	0.0001
Error	80	0.027		

Table 7

Analysis of Variance of Non-Pilots' Altitude Estimates Across Display Modes and Environments

Source	df	MS	F	p less than
Display Mode	2	1.271	19.52	0.0001
Error	46	0.065		
Environment	2	1.671	31.48	0.0001
Error	46	0.053		
Display Mode x Environment	4	0.097	2.99	0.05
Error	92	0.032		

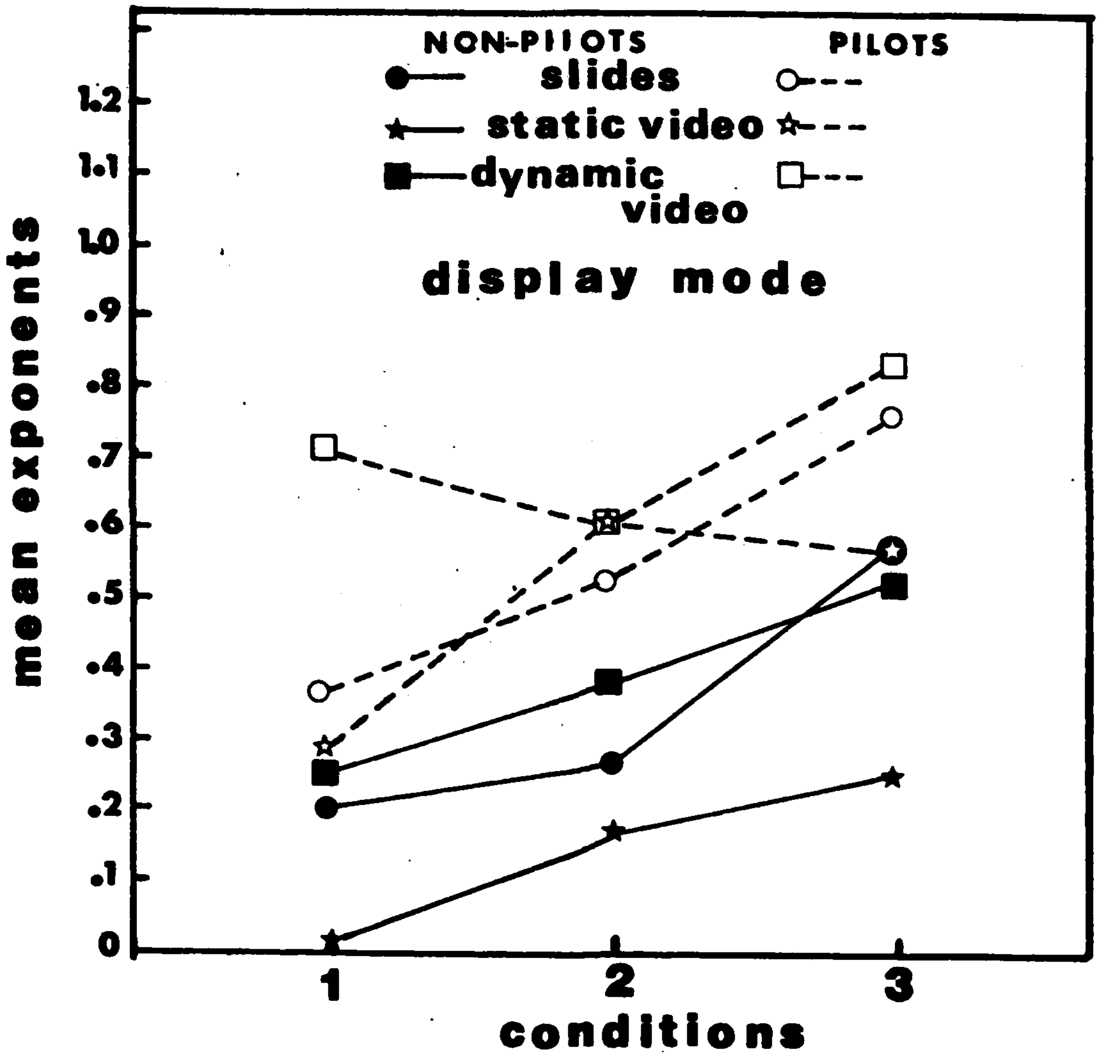

Figure 2. Mean exponents for pilots and non-pilots plotted as a function of display mode and display environment conditions.

Tukey HSD tests were also performed to further explore the specific variables of interest for both groups. For pilots, Tukey HSD tests indicated that display environment 1 (valley floor) differed significantly for each display mode. Tukey tests indicated that for display environment 3 (valley floor with walls and pyramids), the static video mode (display mode 3) differed significantly from the other modes but no difference was found between the dynamic video (display mode 2) and the slide (display mode 1) modes. Also, there was no significant difference between the different display modes for display environment 2 (valley floor with walls). See Table 8. These findings indicate that, in general, as the viewed image either increased it clarity or added optical flow, the pilots' altitude estimations increased in accuracy.

Table 8

Tukey HSD Test Summary for Pilot 0 servers

Group	Variable	Level Comparison Within Variable	Tukey's q value
Pilots	Display Mode 1	E1:E2	3.91*
		E2:E3	5.67**
		E1:E3	9.58**
	Display Mode 2	E1:E2	2.44
		E2:E3	5.35**
		E1:E3	2.79
	Display Mode 3	E1:E2	6.41**
		E2:E3	0.69
		E1:E3	6.11**
	Environment 1	DM1:DM2	6.29**
		DM2:DM3	7.73**
		DM1:DM3	1.44

	Environment 2	DM1:DM2	1.40
		DM2:DM3	0.64
		DM1:DM3	0.75
	Environment 3	DM1:DM2	1.16
		DM2:DM3	5.28**
		DM1:DM3	4.12*

Environment 1 (valley floor) = E1
Environment 2 (valley floor with walls) = E2
Environment 3 (valley floor with walls and inverted pyramids = E3

Display Mode 1 (slides) = DM1
Display Mode 2 (dynamic video) = DM2
Display Mode 3 (static video) = DM3

*p less than 0.05
**p less than 0.01

Table 9

Tukey HSD Test Summary for Non-Pilot Observers

Group	Variable	Level Comparison Within Variable	Tukey's q value
Non-Pilots	Display Mode 1	E1:E2	1.19
		E2:E3	6.35**
		E1:E3	7.46**
	Display Mode 2	E1:E2	2.31
		E2:E3	2.92
		E1:E3	5.19**
	Display Mode 3	E1:E2	3.18
		E2:E3	1.58
		E1:E3	4.78**
	Environment 1	DM1:DM2	1.12
		DM2:DM3	4.88**
		DM1:DM3	3.73
	Environment 2	DM1:DM2	2.12
		DM2:DM3	4.04*
		DM1:DM3	1.97
	Environment 3	DM1:DM2	1.28
		DM2:DM3	5.19**
		DM1:DM3	6.35**

Notation for Table 9 is the same as that for Table 8.

The Tukey HSD test revealed that for the slide display mode, environment 3 was significantly different from the other two environments with a significant difference also obtained between environments 1 and 2. For the dynamic display mode, dispaly environment 3 was significantly different from display environment 2 but not from display environment 1. No signficant differences were found between display environments 1 and 2 and 1 and 3. In the static video display mode, display environment 1 was found to be significantly different from both other environments with no difference between environments 2 and 3. Pilot altitude estimation performance generally became more accurate with increasing scene complexity in each display mode (i.e., from display environment 1 to display environment 3).

In the non-pilot group, results tended to be less equivocal. Examination of the pairwise comparisons (Tukey HSD tests) indicated significant differences for each display environment between the static and dynamic video display modes. See Table 9. In addition, static video environment 3 was found to be significantly different from the slide environment 3. Significant differences were obtained between display environments 1 and 3 for all display modes. Similarly, for the slide display mode, display environment 2 was significantly different from environment 3.

Within each display mode, the pairwise comparisons revealed that, in general, as scene complexity increased, estimation accuracy for the non-pilots increased. This accuracy was

independent of the display mode. The interaction of display mode with display environment for both groups reflected the maximized effectiveness of the environmental cues and the presentation mode. That is, the most accurate estimations were obtained with either the increased clarity of the slide presentation or the optical flow of the dynamic display presentation coupled with the most complex scene (i.e., display environment 3).

DISCUSSION

In general, pilot subjects were more accurate in their altitude estimates than non-pilot subjects, as is shown in Table 5 and Figure 2. It can also be seen that for pilots and particularly for non-pilots that increasing the complexity of the visual display environment usually leads to an increase in the accuracy of altitude estimation, and that the accuracy was relatively independent of display mode. In addition, the dynamic mode of presentation appeared to result in more accurate estimates of altitude, especially when compared to the static video mode. The tendency for slide presentation to produce more accurate altitude estimation compared to static video suggests that clarity or resolution is an important factor in simulator visual displays.

Owen and Warren (1982) have indicated that individuals with no flight experience have still had exposure to global optical flow rates equivalent to those encountered in actual flight situations. However, for nearly all combinations of display modes and environments, the pilots in the present study did

significantly better in altitude estimation than did non-pilots. One possible explanation may be related to the type of experience in terms of the composition of the flow pattern experienced by pilots vs. non-pilots. Prior experience of pilots in detecting altitude change as a function of different altitudes and speeds may provide a better experience with the flow patterns than exposures obtained by non-pilots. There may exist some qualitative differences in the flow patterns experienced by both groups with pilots being sensitive to certain differences. Therefore, the addition of optical flow in the dynamic mode may partially compensate for the lack of complexity and cues in display environment 1 (valley floor). Pilots showed no significant differences between display environment 1 (valley floor) and 3 (valley floor with walls and inverted pyramids) in the dynamic mode which was not the case for non-pilots. It is also possible that this finding may not be due to flying experience, but to the incomplete counterbalancing of pilot subjects and resultant practice effects in this study.

IV: GENERAL CONCLUSIONS FROM EXPERIMENTS 1 AND 2:

Several conclusions may be drawn from the research described in experiments 1 and 2. First, the results from both studies suggest that the method of magnitude estimation is a useful and effective for evaluating simulator visual displays. Second , non-pilot subjects may be used to advantage in developing CIG and future simulator displays. Third, object density and object detail (particularly vertical development) of terrain features appear to be

important cues in altitude estimation, and therefore in low level flight operations. Fourth, clarity or resolution in scene presentation appears to be an important attribute in any simulator display. Fifth, while slides may be a useful training device and can be used in preliminary development of visual environments, a dynamic presentation of the visual environment may add a useful additional element for the development of new visual cues prior to their incorporation in a flight simulator visual display.

V. SUGGESTED DIRECTIONS IN RESEARCH:

Follow-on research should examine the effects of experience with slides and dynamic presentation of low level flight scenes on later simulator performance by pilots. Another study should examine the performance of pilot candidates just before entering undergraduate pilot training as to their ability to more accurately estimate altitudes than a non-pilot population when given slides or static video presentations vs. dynamic scene presentation of visual environments. Other directions in research should involve an investigation of other cues or aspects of vision that may contribute to the maintenance of altitude in low level flight including aerial perspective, field-of-view, accommodation, and flight path angle. In addition, an examination of other psychophysical techniques than magnitude estimation such as the two alternative forced choice technique for the assessment of simulator visual displays should be made.

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